The Washington Water RESOURCE

The quarterly report of the Center for Urban Water Resources Management

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Contents

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Message from the Director

Most of this issue of the Newsletter is dedicated to a summary report of the three-year project, "Stream Quality Indices," which has been conducted under a grant from the Washington State Department of Ecology to professors Eugene Welch, Richard Horner, James Karr, and Brian Mar. They and a host of graduate students, particularly recent Ph.D. graduate Christopher May, have been exploring various measures of urbanization and stream conditions, and they have been looking for useful and consistent relationships between these parameters. Their examples have been rural, suburban, and urban streams in the greater Seattle area, and their results have generated a tremendous amount of regional and national interest already. I am delighted to present summaries of various aspects of their work in this issue.

As this project winds down, a number of others are rising up to take its place. Our three-year study of urban stream rehabilitation, funded by the U. S. Environmental Protection Agency and described in the Summer 1996 Newsletter, begins in earnest this spring with the selection of target watersheds for a quantitative assessment of the processes by which urban development causes stream degradation. Other work on characterizing groundwater contamination, using environmental indicators, and evaluating several types of water-quality facilities are beginning or in progress; a growing regional interest in different types of environmental monitoring and benchmarks suggests that additional projects are soon likely in this arena as well. I am particularly hopeful in the possibilities for collaborative research with multiple local jurisdictions that should begin to arise from the new "Watershed Forums" in the Green, Cedar, Sammamish, and Puget Sound watersheds of Western Washington, because these entities are most likely to combine both the interests and the resources of multiple jurisdictions within the kind of geographical context that best frames water-resource issues.

This newsletter is also the last that will be sent off of our 1996 subscriber list. You should have received a renewal notice about a month ago, and we have already received most back. If you have not sent your renewal back yet, please do so soon—we do not send out reminder notices! I hope that the value to you of remaining a subscriber continues to increase, and we look forward to an ever-growing base of support, and of informed users, in the year ahead.

Derek Booth ❖

The Washington Water Resource is the quarterly publication of the Center for Urban Water Resources Management at the Department of Civil Engineering, University of Washington, Box 352700, Seattle, WA 98195.

Assessment of Cumulative Effects of Urbanization on Small Streams in the Puget Sound Lowland Ecoregion: A Summary Report of the ***Stream Quality Indices*** Project

by C. Cooper, R. Horner, J. Karr, B. Mar, C. May, J. Olthof, E. Welch, and A. Wydzga: University of Washington, Civil and Environmental Engineering and Science Program

BACKGROUND

The Puget Sound region is experiencing an increase in urban development that is rapidly expanding into areas containing much of the remaining natural aquatic ecosystems. In the Puget Sound lowland (PSL) ecoregion, the aquatic ecosystems most directly affected by the current pattern of watershed land-use are small streams and associated wetlands in the lowland ecoregion. There has been significant degradation of stream quality in the region due to the cumulative effects of timber harvest, agriculture, and urbanization.

This study was designed to assess the impact of urbanization and development on small lowland streams. A conceptual model of this design is illustrated below:

Watershed and Riparian Characteristics => Instream Habitat Conditions => Aquatic Biota

A sub-set (22) of small, PSL stream watersheds was chosen to represent a range of development levels from relatively undeveloped (reference) to highly urbanized (Figure 1). The attributes of the stream catchments were established using standard watershed analysis methods (aerial photos, basin plans, and field-surveys). Impervious surface coverage, riparian integrity (quantity and quality), instream (salmonid) habitat, chemical water-quality constituents, and aquatic biota were analyzed on watershed and stream-segment scales. Discharge was continuously monitored by local agencies on 10 of the study streams. Chemical water-quality monitoring (baseflow and storm event) was also performed (23 sites). Macroinvertebrate sampling was performed in 31 reaches. Extensive assessment of instream physical habitat were made on 120 stream-segments, each representing local physiographic and land-use conditions from the headwaters to the mouth of the stream. Current and historic salmonid abundance data was obtained from local governmental, private, and tribal sources.

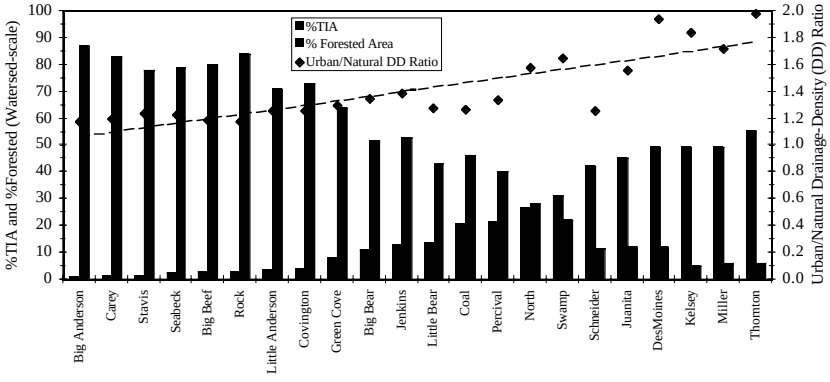

Figure 1: Watershed urbanization in Puget Sound lowland (PSL) streams.

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RESULTS AND DISCUSSION

The initial discussion will consider the direct linkages between watershed and riparian characteristics and instream biota, including macroinvertebrates and salmonids. The condition of the benthic macroinvertebrate community was expressed in terms of a multi-metric PSL Benthic Index of Biotic Integrity (B-IBI) developed by Kleindl (1995) and based on the original B-IBI of Karr (1991). In addition, fish abundance data gathered from local agencies was also utilized as a more direct measure of biological integrity. The abundance ratio of juvenile coho to cutthroat trout originally utilized by Lucchetti and Fuerstenberg (1993) was used as a measure of salmonid community integrity.

Figure 2 shows the relationship between B-IBI scores and urbanization (%TIA). Only reaches with a cumulative upstream %TIA < 5% exhibited an B-IBI of 32 or greater (with 45 being the maximum possible score). There also appears to be rapid decline in biotic integrity with the onset of urbanization (%TIA) between 0-10%. On the other end of the development spectrum, it appears unlikely that any reach with a %TIA > 45% will have a B-IBI greater than 15 (minimum B-IBI is 9). There are exceptions to these apparent thresholds as would be expected with the complexity found in most stream ecosystems. This reaffirms the intuitive conclusion that development is influencing stream biota via multiple paths that are not necessarily consistent from stream to stream. All B-IBI between 25 and 32 were associated with reaches having a %TIA < 10%, with eight notable exceptions. These eight reaches had upstream %TIA values from 25-35% and yet had a biotic integrity much higher than other streams in this range of development (typical suburban land-use range). All eight had a large fraction of their riparian wetlands intact (> 15% of the stream corridor) and all but one had overall wider riparian buffers (> 60% of the stream corridor with buffer width > 30 m). These observations indicate that maintenance of a wide, natural riparian buffer zone may mitigate some of the effects of watershed urbanization.

Chemical water-quality constituents were monitored under baseflow and stormflow conditions. Baseflow conductivity (us/cm) was found to be strongly correlated with basin development level (r = -0.91). Coal Creek was a confirmed outlier due to the residual effects of historic coalmining in its headwaters. While conductivity is a non-specific chemical parameter, it is a surrogate for total dissolved solids and alkalinity, and an excellent urbanization indicator (Olthof, 1994). Storm event mean concentrations (EMC) of several chemical constituents, including total phosphorus (TP), total zinc (TZn), and total suspended solids (TSS), were found to be correlated with basin imperviousness (Bryant, 1995). In most cases the relationships were fairly strong, however water-quality criteria were rarely violated except in the most highly urbanized watersheds (%TIA > 45%). Sediment zinc and lead also indicated a strong relationship with urbanization, again showing the highest concentrations in the most developed basins. As with other recent studies (Pitt et al, 1995), these findings indicate that chemical water-quality of urban streams is not significantly degraded at the low impervious levels, but may be an important factor in highly urbanized streams.

In contrast to chemical water-quality, changes in hydrologic regime appear to be significant earlier in the development process. The ratio of modeled 2-year stormflow to mean winter baseflow, as an indicator of development-induced hydrologic fluctuation, shows a fairly strong relationship with urbanization (Figure 3). The ratio is proportional to the relative stream power, and thus is representative of the hydrologic stress on instream habitat and biota exerted by stormflow relative to baseflow conditions.

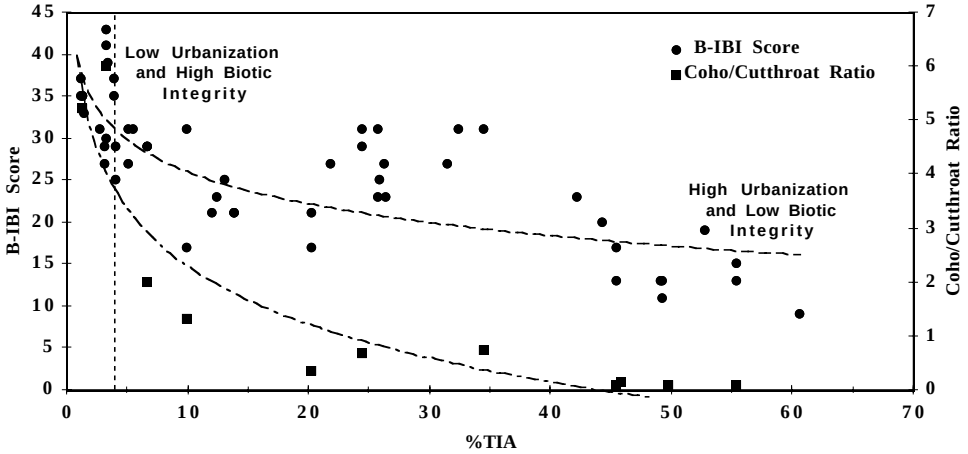

Figure 2: Biological integrity in Puget Sound lowland (PSL) streams.

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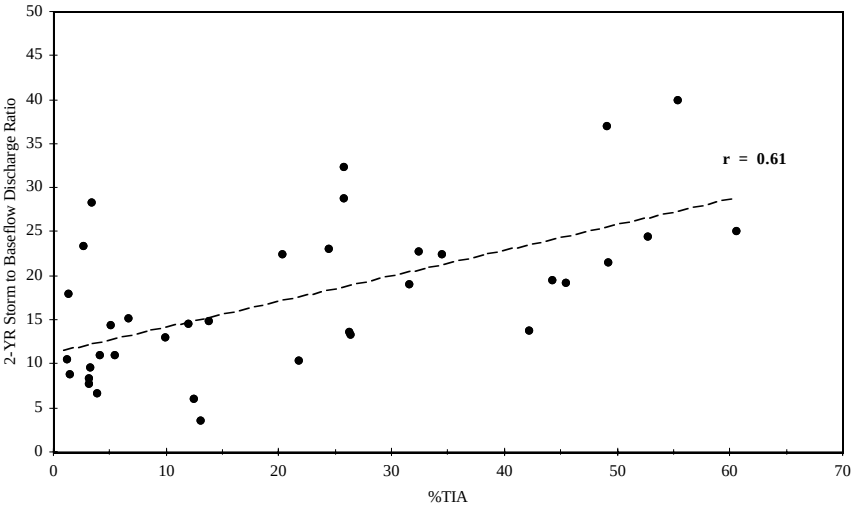

Figure 3: Change in basin hydrologic regime with urbanization in Puget Sound lowland (PSL) streams.

Large woody debris (LWD) is a ubiquitous component in streams of the PNW. There is no other structural component as important to salmonid habitat as LWD. LWD performs critical functions in forested lowland streams, including dissipation of flow energy, streambank protection, streambed stabilization, sediment storage, and providing instream cover and habitat diversity (Bisson et al, 1987; Masser et al, 1988; Gregory et al, 1991). And, although the influence of LWD may change over time, both functionally and spatially, its overall importance is significant and persistent. As was expected, measures of salmonid rearing habitat, including % pool area, pool size, and pool frequency, were strongly linked to the quantity and quality of LWD in PSL streams. While LWD quantity and quality were negatively affected by urbanization (Figure 4), many of the natural, undeveloped streams also had a lack of LWD (especially very large LWD). This appears to be a residual effect of historic timber-harvest and "stream-cleaning" activities. Nevertheless, with few exceptions (habitat restoration sites), high quantities of LWD occurred only in streams draining undeveloped basins (%TIA < 5%).

The bottom substratum is critical habitat for salmonid egg incubation and embryo development, as well as most macroinvertebrates. Streambed quality can be degraded by deposition of fine sediment (< 0.85 mm). Fine sediment sampling (McNeil method) was performed in the same reaches as macroinvertebrates were sampled and the intragravel dissolved oxygen (IGDO) was also monitored throughout two separate incubation periods. Low IGDO levels are typically associated with fine sediment intrusion into the salmonid redd, although local conditions can have a strong influence on intragravel conditions and the distribution of fine sediment (Chapman, 1988). Spawning salmonids can also reduce the sediment content of the substrata, at least temporarily. Measurement of instream DO coincident with IGDO allowed for the calculation of a IGDO/DO interchange ratio. In all but one case, the mean interchange ratio was > 80% in the undeveloped, reference reaches (%TIA < 5%). As basin development (%TIA) increased above 10%, there were numerous reaches in which the mean interchange ratio was well below 80% (as low as 30%). While these DO levels are not lethal, low IGDO

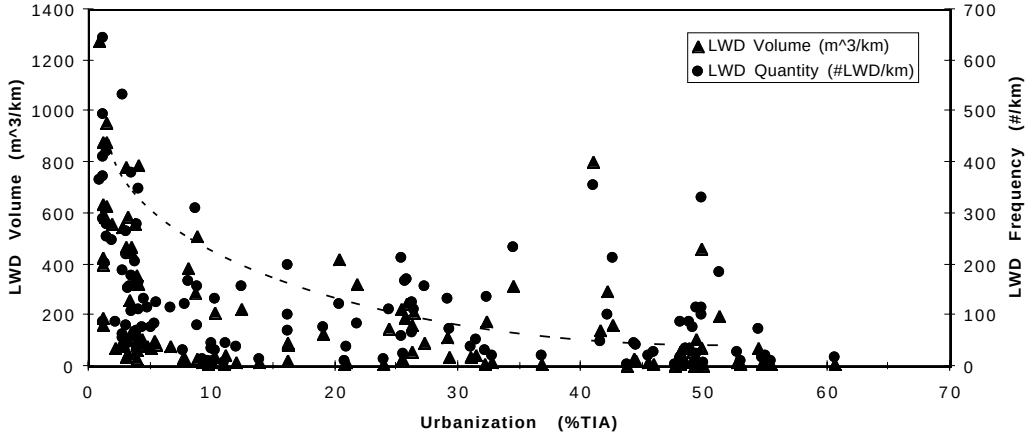

Figure 4: Large woody debris (LWD) quantity in Puget Sound lowland streams.

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levels during embryo development can reduce survival to emergence (Chapman, 1988). Fine sediment levels (% fines) were also related to upstream basin urban development, but the variability, even in reference reaches was quite high. However, % fines did not exceed 15% until %TIA exceeded 20%. In the highly urbanized basins (%TIA > 45%), the % fines were consistently > 20% unless flushed by stormflows (Wydzga, 1997).

The final linkage to be discussed involves the relationships between instream habitat and aquatic biota. Given that relationships were identified between basin development level and both instream habitat and biological integrity, it is reasonable to hypothesize that similar associations exist between physical habitat and biological functioning. As a general rule, instream habitat conditions (both quantity and quality) correlated well with B-IBI and coho/cutthroat ratio. Measures of spawning and rearing habitat quality were closely related to the coho/cutthroat ratio. As might be expected, measures of streambed quality were also closely related to the B-IBI. Chemical water quality also appears to influence aquatic biota even though chemical constituents do not approach levels known to be harmful except in highly urbanized streams. For example, baseflow conductivity, at the low levels generally found in this study, is by itself innocuous. The same is true of the concentrations of representative metals. However, little is known of the possible synergistic effects of various pollutants or the cumulative effects of long-term exposure on stream biota.

Because of its known importance to macroinvertebrate community composition, the effect of fine sediment on stream benthos was examined in detail. Of the B-IBI scores > 30, all but one were associated with reaches having < 15% fines. In addition, all but 2 of the reaches (%TIA > 45%) with B-IBI scores < 20, had > 20% fines. Similar relationships exist between the B-IBI and substrata embeddedness, streambed particle-size distribution, and the IGDO/DO ratio. In general, benthic macroinvertebrates appear to be quite sensitive to relatively small alterations in the substratum (Wydzga, 1997).

IMPLICATIONS FOR WATERSHED MANAGEMENT

Results of the PSL stream study have shown that a host of physical habitat and biological characteristics change with increasing urbanization in a more continuous rather than threshold fashion. Although the patterns of change differed among the attributes studied and were more strongly evident for some than for others, physical and biological measures generally changed most rapidly during the initial phase of the urbanization process as %TIA increased to the 5-10% range. With greater urbanization, the rate of degradation of habitat and biologic integrity usually became more gradual. There was direct evidence that altered watershed hydrologic regime was the probable underlying cause for the overall changes observed.

Chemical water quality constituents and concentrations of metals in sediments did not follow this pattern. These variables changed little over the urbanization gradient until imperviousness (%TIA) approached 45%. Even then water column concentrations did not surpass aquatic life criteria, and sediment concentrations remained far below freshwater sediment criteria. As urbanization (%TIA) increases above the 60% level, with pollutant concentrations rising rapidly at that point, it is likely that the role of water and sediment chemistry becomes more important biologically.

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Center Projects

Current and Recently Completed Projects at the Center

- Maintenance of Failed Biofiltration Swales (see Summer 1996 Newsletter): Three swales in north-central King County were reconstructed this fall to revised design standards and replanted with a specially developed mixture of grass seeds. Field measurements on these swales, other control swales, and parallel greenhouse experiments are continuing through this next winter and spring.
- Development of Stream Quality Indices (see accompanying article and new publications)
- Soil Amendments to Improve Infiltration (see Summer 1995 Newsletter). A full-scale field test of the hydrologic, economic, and aesthetic effects of soil amendments is being planned for a new development in the city of Redmond for 1997; more information will be forthcoming in a subsequent issue of the Newsletter.
- Lakemont Boulevard Construction Oversight (see Fall 1995 Newsletter)
- Infiltrative Parking Lot Surfaces (see Fall 1996 Newsletter)
- Environmental Benchmarks in Citizen-Based Watershed Planning (see Summer 1996 Newsletter)
- Eastgate Water-Quality Pond Performance (see Summer 1996 Newsletter)

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Biological community alterations in urban streams are clearly functions of many variables representing conditions in the immediate and more remote environment. In addition to urbanization level, a key determinant of biological integrity appears to be the quantity and quality of the riparian area available to buffer the stream ecosystem, in some measure, from negative influences in the watershed. The apparent linkage between watershed, riparian, instream habitat, and biota shown here supports management of aquatic systems on a watershed scale.

There appears to be a set of necessary, though not by themselves sufficient, conditions for the highest level of biological functioning. If maintenance of that level is an adopted goal, then this set of conditions constitutes standards that must be achieved if the goal is to be met. Using the PSL streams as an example, if that level is taken to be a B-IBI of at least 35 or a coho/cutthroat ratio of 5, imperviousness must be very low (%TIA < 5%), unless mitigated by extensive riparian corridor protection, BMPs, or both. It is also apparent that LWD quantity and quality must be restored to pre-development/logging levels for natural instream habitat diversity to be realized. Of course, prior to undertaking any habitat enhancement efforts, the basin hydrologic regime must be restored to near-natural conditions. Results suggest that resource managers should concentrate on preservation of high-quality stream systems through the use of land-use controls, riparian buffers, and protection of critical habitat. Enhancement and mitigation efforts should be focused on watersheds where ecological function is impaired but not lost. Downstream changes to both the form and function of stream systems appear to be inevitable unless limits on the extent of urban development itself are instituted.

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Center Projects

Upcoming Projects at the Center

Urban Stream Rehabilitation in the Pacific Northwest (Spring 1997-Spring 2000): (see Summer 1996 Newsletter)

Hydrogeologic Pathways, Duwamish Corridor (Winter-Fall 1997): (see Fall 1996 Newsletter; work presently scheduled to begin this month)

PROFESSIONAL ENGINEERING PRACTICE LIAISON (PEPL) Program

The PEPL (PROFESSIONAL ENGINEERING PRACTICE LIAISON) Program, in cooperation with the Center for Urban Water Resources Management, offers a continuing education program in urban water resources management.

As part of the benefits extended to supporters of the Center for Urban Water Resources Management, member organizations submitting five or more registrations for the same course may deduct $30 per registration for a 1-day course, $35 for 1.5-day, $45 for a 2-day course, $50 for a 2.5-day course, and $60 for a 3-day course.

For further information on the *Urban Surface Water Management Continuing Education Program* or on any of the courses on the next page, please contact:

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Hydrologic Simulation of the Klahanie Catchment, King County, Washington, With and Without a Landscape Consisting of Soil Amended with Compost

by Eric J. Hielema, M.S. Thesis (1997)

The conversion of forested hillslopes in the Puget Sound Region to residential use produces a wide range of environmental impacts. Problems that are becoming more common in the Puget Sound area include increases in flooding magnitude and frequency, increased erosion in streams and rivers, and problems of low streamflow during the drier months. The current pre-construction practice of stripping the native topsoil to expose the harder layers of glacial till, done to take full advantage of till's strength characteristics, radically changes the hydrology of a hillslope. The development of native hillslopes using this practice increases the volume of quick response run-off from storms and decreases the longer term baseflows which are necessary to maintain streamflow during the drier periods. The increases in streamflow production are outstripping the hydraulic and biological capabilities of many of the natural aquatic systems across the region.

This study examined the potential benefits to stormwater management of residential landscaping with a compost-amended soil. At the University of Washington, the subsurface and surface runoff from seven test plots, with varying amounts and size grades of compost amendment, have been monitored for over 2 years. The plots were designed to best represent the scale of a typical residential lawn. The data collected thus far demonstrate significantly decreased peaks in the hydrographs of plots amended with compost when compared against plots without amendment.

A related study at the University of Washington has calibrated the Hydrologic Simulation Program — FORTRAN (HSPF) to two of the soil amendment test plots in order to quantify the potential hydrologic benefits of soil amendment. We have now substituted the calibrated HSPF input parameters from the amended soil plots into a calibrated HSPF model of the Klahanie catchment in King County, to explore how runoff from that development might have been altered by widespread application of soil amendment. Many problems surfaced during the substitutions of the soil plot parameters for the Klahanie parameters, largely a consequence of the scale of the soil plots being four orders of magnitude smaller than that of the Klahanie catchment. These efforts are demonstrating significant stormwater-management benefits from using amended soil, but differences in the physical structure between full-scale catchments and the soil plots have thus far prevented full quantification of those benefits. ❖

New Publications Available Through the Center

To order these or any other publications, or to receive a complete listing of available titles, contact the Center's publication distribution service using the order form on page 6.

- Effect of Road Shoulder Treatments on Highway Runoff Quality and Quantity: by Matthias St. John, 1997, 173 p.

The most notable manifestation of urban development is the increase in the amount of impervious surfaces that cover a landscape. The amount of transport-related imperviousness typically accounts for 60 percent of the total impervious cover. Therefore, attempts are being made to evaluate, and subsequently minimize, the water quality effects imposed by runoff from roads.

This research examined the role that road shoulders play in the stormwater runoff process. The goal of the research was to determine the type of shoulder treatment that yields the least quantity of runoff of the highest quality. Three types of shoulder materials were tested: conventional asphalt, gravel, and porous asphalt. Porous asphalt allows water to penetrate and flow through the pavement to a sublayer, and can be used in place of conventional asphalt on low-traffic roadways. Each of the three shoulder materials was tested in duplicate in 35-m^2 (400-ft^2) test sections on the road shoulder adjacent to the NE Woodinville-Duvall Road north of Redmond, WA. Stormwater runoff from the heavily traveled two-lane road flowed onto the shoulder test sections and was collected in a stormwater collection system at the base of the test sections. Flow-weighted composite samples were collected, and both runoff quantity and quality were evaluated.

Several distinct trends were identified based on the results from 11 storms monitored between November 1995 and August 1996. The porous asphalt shoulders demonstrated the greatest potential as a replacement for traditional asphalt shoulders. During typical wet season storms (0.76 cm [0.3 in]), the porous asphalt and gravel shoulder test sections can reduce runoff volumes by approximately 85 and 30 percent respectively, compared to the runoff volumes from the conventional asphalt test sections. The ability of the porous asphalt shoulders to reduce pollutant loads far exceeded the load reductions by the gravel and conventional asphalt shoulders. During typical wet season storms the solids and pollutant loads from the porous asphalt shoulders were less than 10 percent of the loads from the conventional asphalt shoulders. The gravel shoulders yielded load reductions ranging from 10 to 70 percent lower than the conventional asphalt, though ortho-phosphorus loads exceeded those from the conventional asphalt shoulder by nearly 30 percent.

Removal rates were highest for those pollutants that were correlated with total suspended solids ($0.70<r^2<0.95$), indicating that physical mechanisms of settling and filtration were critical in removing pollutants from the runoff from both porous asphalt and gravel shoulders. The porous asphalt shoulders were more efficient at removing soluble pollutants, particularly ortho-phosphorus, compared to the conventional asphalt and gravel shoulders. After one year of use the porous asphalt shoulders showed no sign of clogging, maintaining infiltration rates of 4445 cm/hr (1750 in/hr). Price = $26.00 (publication no. K14)

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1997 Professional Engineering Practice Liaison (PEPL) Courses

March 12
Successful Negotiation Skills in Construction Projects

March 25 and 26
Hydrologic Modeling and Design of Retention/Detention Facilities

April 16 and 17
Storm and Surface Water Monitoring

May 6 and 7
Achieving *Real* Success as a Project Manager

May 14 and 15
Design and Retrofit of Culverts in the Northwest for Fish Passage

June 10 and 11
Use of Constructed Wetlands for Improving Stormwater Quality

September 23 and 24
Alternative On-Site Stormwater Management Techniques

November 5 and 6
Specifications and Construction Techniques for Stream and Wetlands Projects

December 11 and 12
Stormwater Treatment by Media Filtration

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PUBLICATIONS (from page 9)

- Assessment of Cumulative Effects of Urbanization on Small Streams in the Puget Sound Lowland Ecoregion: Implications for Salmonid Resource Management: by Christopher W. May, 1996, 383 p.

Instream physical habitat characteristics, riparian conditions, chemical water-quality, and biological attributes of 22 Puget Sound Lowland (PSL) streams (120 survey reaches), were studied over a gradient of development, during a three-year period to determine cause-effect relationships between urbanization and stream quality. This dissertation presents much of the data, analyses, and conclusions of the Stream Quality Indices project, including the material presented in the accompanying article in this issue of the Newsletter.

As the level of basin development (%TIA) increased above 5%, there is a precipitous initial decline in biological functioning and the physical habitat conditions necessary to support that functioning. That effect was evident at the onset of human disturbance and was followed by a steady decline in biological indicators. The highest levels of stream quality, measured by the benthic index of biotic integrity (B-IBI) > 33 and a coho:cutthroat abundance ratio >2, along with natural instream habitat conditions, were found only in streams with a %TIA < 5%. A significant loss of ecological function appears to occur in PSL streams at a basin impervious level (%TIA) of approximately 45%.

Current regulations, mitigation efforts, and best management practices (BMPs) do not appear to be effective in preventing a degradation in stream quality. Results suggest that resource management should focus on preservation and protection of high quality stream ecosystems (%TIA < 5%) through watershed development limits and maintaining riparian corridor integrity. Based on the findings of this study, protection of riparian corridors should be a high priority. Rehabilitation efforts should be concentrated on streams draining watersheds in the low to moderate range of development (10-20 %TIA). Although recovery to near-pristine conditions cannot be expected in moderate to highly developed stream basins, mitigation efforts should nevertheless continue in an effort to improve stream quality to a level supportive of natural biota. Price = $57.50 (publication no. K15)

- The Effects of Urbanization and Fine Sediment Deposition in Puget Sound Lowland Streams: by Alexandra M. Wydzga, 1997, 80 p.

The objective of this study, part of the Stream Quality Indices project, was to investigate the percent of fine sediment (<0.85 mm) present in the stream substratum, and its relationship to both the urbanization of the watershed and the biological integrity of the stream. Forty-six sites on 20 streams in the Puget Sound Lowlands were studied. Sediment substratum samples were collected in riffles using a McNeil sampler and sorted through sieves in the summers of 1994 and 1996. Habitat assessment surveys quantified specific habitat features in each stream (May, 1996 [CUWRM publ. K15]). The benthic index of biological integrity (B-IBI) was used as an indicator of the quality of the benthic macroinvertebrate assemblage. The total area of impervious area (%TIA) was calculated to represent the level of urbanization in the watershed.

The percent of fine sediment in the substratum increased with urbanization (%TIA). Highly urbanized streams (%TIA>45%) had more fine sediment in the substratum, fewer pieces of large woody debris, less riparian zone, less pool habitat, higher 2-year peak flows, and lower intergravel dissolved oxygen. B-IBI scores ranged from the lowest score of biological integrity (<20) to the highest (>32) in streams which correspondingly changed from less than 15% fine sediment to more than 22% fine sediment. The percent of fine sediment was found to be a good indicator of substratum conditions for benthic macroinvertebrates. The percent of fine sediment provided a necessary, but a not alone sufficient, condition to ensure high levels of biological integrity. Price = $12.00 (publication no. K16)

- Hydrologic Effects of Urbanization on Puget Sound Lowland Streams: by Catherine Cooper, 1996, 83 p.

The objective of this study, part of the Stream Quality Indices project, was to examine how the hydrologic effects of urbanization contribute to degradation of the biotic integrity of urban streams. The effects of an altered hydrologic regime on in-stream habitat conditions, and the resulting effects of changed habitat conditions on stream biota, were examined. Forty-one sites on 20 small streams in the region were studied. The 2-year peak flow for each stream site was estimated using hydrologic models; field measurements provided average base flow values; habitat assessment surveys quantified specific habitat features in each stream.

The magnitude of alteration of the hydrologic regime due to urban watershed conditions was best represented by the ratio of 2-year peak flow to winter base flow. Two-year peak flow/winter base flow increased with increasing urbanization. Habitat features were affected by an altered hydrologic regime. Fewer pieces of large woody debris, less

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pool habitat, reduced pool cover, decreased median substratum particle size, and increased substratum embeddedness occurred with increasing values of 2-year peak flow/winter base flow. Values of 2-year peak flow/winter base flow < 20 appeared acceptable for maintaining levels of biotic integrity close to those found in unimpacted streams in the region. However, 2-year peak flow/winter base flow <20 did not guarantee a stream with high biotic integrity. The biotic degradation seen in urban streams is the result of many different factors acting together. Nevertheless, an altered hydrologic regime may be an important process that accounts for the changes observed in stream habitat and stream biotic communities in urban watersheds. Price = $12.50 (publication no. K17) ❖

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